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MACHINABILITY STUDY ON DRILLING OF Al7075/Al_2O_{3P} /GR_P HYBRID METAL MATRIX COMPOSITES

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Abstract

In this paper, an investigation has been made to explore the thrust force, torque and surface roughness that contain important information related to the quality of the hole produced during the drilling of hybrid aluminum metal matrix composites -Al7075/Al_2O_{3p} /Gr_p using low cost HSS twist drill bits. These composites are increasingly being used in aerospace, marine, automobile and mineral processing industries owing to their superior mechanical and wear properties. In this study, hybrid composites were reinforced with the hard ceramic (0 and 3 wt. % of Al_2O_3) and soft solid lubricant (2, 4 and 6 wt. % of graphite) of particle sizes 40µm. These composites with varying percentages of Al_2O_3 and graphite were fabricated by using stir casting method in a controlled atmosphere. Uniform distribution of reinforcing particles was confirmed by optical microscopy and SEM views. The experiments were designed using Taguchi's L18 orthogonal array (2^1 x 3^4) to examine the machinability of these composites during drilling. The drilling experiments were carried out at various speeds (244, 445, 890 rpm), point angles (108^0, 114^0 and 118^0), and chisel point thickness (2, 1.7, 1.4mm) to study their effect and reinforcing particles on thrust force, torque and surface roughness,. Analysis of variance and main effects plots were used to analyze the experimental data and find the optimal combinations of various input parameters. The results based on these analyses showed that thrust force is mainly affected by point angles of drill bit. Torque is mainly affected by wt% of graphite and point angles. The thrust force and torque have similar effects of point angles. The surface roughness decreased with increase of wt% of alumina and increases with increase of the speed.

Keywords: Al7075 composites, drilling, thrust force, torque, surface roughness.

1. INTRODUCTION

Aluminium alloys are ideal engineering materials for automobile, aerospace and mineral processing industries for various high performing components owing to their good physical and mechanical properties. Among several series of aluminium alloys, aluminium alloy 7075 possesses high strength to weight ratio, high toughness, excellent thermal conductivity and corrosion resistance. Hybrid metal matrix composites (HMMC) are engineering combinations of two or more reinforcements in which expected properties are achieved by bringing the combined advantages of both matrix and reinforcement into full advantage, which gives us a rather high degree of freedom in material design. But these composites have very low machinability which is attributed to the presence of hard ceramic reinforcements. This results in high cutting forces, tool wear rate and poor surface finish. In case of drilling, carbide/diamond coated drills, cemented carbide drills and diamond drills can be used for high quality holes, but they are very expensive and not widely available. Hence, HSS drill bits are still preferred owing to their low cost and ease of availability [Riaz et al., 2010].

The production of the holes in metal matrix composites is of great interest because machining of composites is difficult due to the anisotropic and non-homogeneous structure of the composites and high abrasiveness of the reinforcements. Many authors have carried out machinability studies on drilling of various composites. Teti [--] presented an overview of the various issues involved in drilling of composite materials and suggested that drilling can be applied to composite materials

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provided the proper tool design and operating conditions are adopted. Tsao and Hocheng [--] evaluated and predicted the thrust force and surface roughness in drilling of carbon fiber/epoxy matrix composite material. The experimental results indicated that the feed rate and the drill diameter are the most significant factors affecting the thrust force, while the feed rate and spindle speed contribute the most to the surface roughness. Basavarajappa et al. [5] explored the influence of cutting parameters on drilling characteristics of hybrid metal matrix composites-Al2219/15SiCp and Al2219/15SiCp–3Gr using Taguchi design of experiments and provided an insight on how performance characteristics greatly depend on feed rate rather than speed. Paulo Davim [6] studied the influence of cutting parameters and cutting time on drilling of A356/20/SiC_p-T6 and obtained correlation of cutting velocity, feed rate and cutting time with tool wear, with the specific cutting pressure and surface roughness. Fernandez and Cook [7] discussed the common problems like excessive tool wear, poor surface finish, delamination of fibres and chip removal associated with the drilling of carbon composites. Further, their investigation on the thrust force and torque produced showed that they are a function of feed, drill bit type, work piece thickness and tool wear. Veeresh Kumar et al. [8] prepared the composites Al6061-SiC and Al7075-Al_2O_3 through stir casting and demonstrated that the reinforcements contributed to the increased hardness, tensile strength and wear properties. Rajmohan et al. [4] optimized the machining parameters with multiple performance characteristics in drilling hybrid metal matrix Al356/SiC-mica composites and concluded that feed rate and type of drill are the most significant factors which affect the drilling process.

An extensive literature survey indicates that major work was focused on the machinability studies on variety of aluminium alloys either with SiC or Al_2O_3. Traditionally, graphite is a natural lubricant, which eases the machining. Little research work has been done on the incorporation of graphite in Al_2O_3p composite. In view of the above, number of Al7075 composites are prepared with varying percentages of graphite and Al_2O_3 to investigate the machining performance in drilling of these composites. The Taguchi design of experiments and analysis of variance are used to find the effect of various machining parameters on drilling of both these composites.

2. DESIGN OF EXPERIMENTS USING TAGUCHI METHOD

Robust design is an engineering methodology to optimize the product and process conditions which are least sensitive to the causes of variation. Taguchi's parameter design is an important tool for robust design. In this paper, five input parameters are considered viz. Al_2O_3% (0 and 3% wt.), Gr% (2%, 4% and 6% wt.), speed (244, 445, 890 rpm) , point angles (108^0, 114^0 and 118^0) and chisel point thickness (2, 1.7, 1.4mm) to study their effect on TF, TQ and SR. The L18 orthogonal array is selected as it can accommodate one two level parameter and four three level parameters (degrees of freedom =9). L18 orthogonal array with various levels of the input process parameters and obtained experimental results are shown in Table 1. The data collected from all the experiments is analyzed to determine the effect of various input parameters. Analysis of variance (ANOVA) is a mathematical technique used to determine percentage contribution of individual parameters. In this study, the analysis of the experimental results is carried out based on the main effects plots and ANOVA. The interaction effects are not considered in this paper.

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Table 1 L18 orthogonal array and experimental results

Trail No	% Al_2O_3	% Gr	Speed (rpm)	Point Angle (deg)	Chisel Point Thickness (mm)	TF (N)	TQ (Kg-m)	SR (Ra, µm)
1	0	2	244	108	2	79.54	0.148	2.001
2	0	2	445	114	1.7	163.91	0.251	3.195
3	0	2	890	118	1.4	66.75	0.181	5.008
4	0	4	244	108	1.7	84.56	0.19	2.228
5	0	4	445	114	1.4	161.48	0.335	3.707
6	0	4	890	118	2	91.93	0.218	5.156
7	0	6	244	114	2	117.11	0.116	2.305
8	0	6	445	118	1.7	66.86	0.094	3.755
9	0	6	890	108	1.4	57.69	0.148	5.172
10	3	2	244	118	1.4	83.16	0.2045	1.854
11	3	2	445	108	2	81.68	0.133	2.001
12	3	2	890	114	1.7	159.35	0.2215	4.433
13	3	4	244	114	1.4	95.2	0.239	1.928
14	3	4	445	118	2	62.69	0.145	2.072
15	3	4	890	108	1.7	51.74	0.109	4.853
16	3	6	244	118	1.7	97.76	0.1	1.978
17	3	6	445	108	1.4	64.51	0.139	2.095
18	3	6	890	114	2	146.15	0.171	5.057

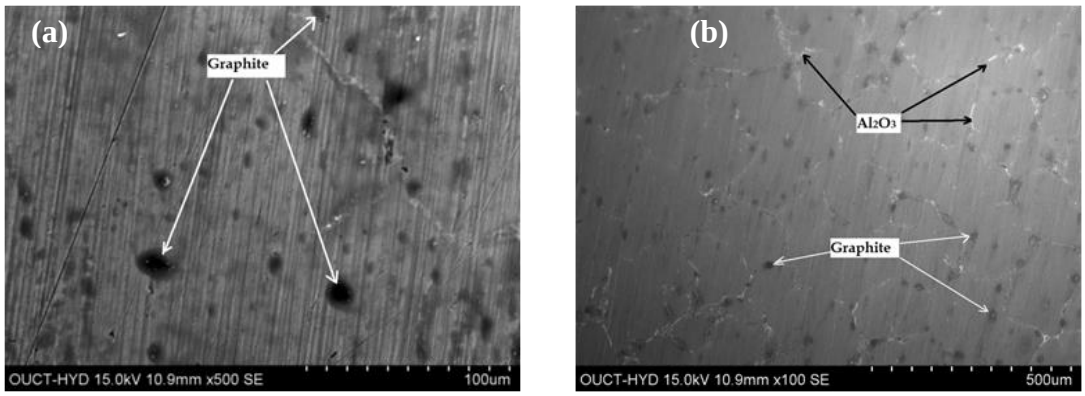

Fig. 1 SEM views of (a) Al7075, Al_2O_3-0%, Gr -6% (b) Al7075, Al_2O_3-3%, Gr-4%

3. EXPERIMENTAL PROCEDURE

Six HMMC specimens of Al7075 matrix with different combinations of alumina (2 levels) and graphite (3 levels) of average particle size 40µm are prepared using stir casting process with proper processing conditions [-----]. Each specimen was machined to the size of 100mm x 40mm x 10mm blocks. The thorough stirring led to the formation of a near homogeneous mixture with particulate alumina & graphite evenly distributed in Al7075 matrix. Two sample specimens are shown in Fig. 1. Drilling experiments were conducted on conventional radial drilling machine (Make- New Bharat Engineering Works Ltd. India, Type-30/1000) using HSS drill bits. Three drill bits of different point angles viz. 108^0, 114^0 and $118^0$and diameter of Ø10 mm are used. The feed and depth of cut were kept constant during the drilling operation. All experiments were performed under dry drilling conditions. Thrust force and torque developed during drilling were obtained with strain gauge based drill tool dynamometer. A proper fixture was firmly held on top of the dynamometer. The experiments were repeated twice to reduce the experimental errors. SR values of drilled holes were

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taken with the surface roughness tester (Make and Model: Mahr, Marsurf M400) at cut-off length of 2.5 mm. The SR is recorded at four different locations and the average values of all readings was taken for the analysis [---].

4. RESULTS AND DISCUSSION

4.1 INFLUENCE OF PROCESS PARAMETERS ON TF

Thrust is the reaction force against the drill's advance into the work piece. From ANOVA Table 2, one can observe that the most significant factor is the point angle (74.78%), hence it has a statistical and physical significance and other four parameters do not have statistical. This indicates that the TF is independent of the composition of the work piece, speed and chisel point thickness. These results are consistent with the work of Ramulu et al. (Ramulu et al., 2002. It is observed in the literature [--] that the TF and TQ increases with the increase of point angles. But, it can be seen from Fig. 1 that TF has resulted in higher value for point angle 108^0 than point angle 114^0. Later, it dropped again for point angle 118^0. This may be due to interactive effect of %Gr which act as the natural lubricant during the drilling and ease the machining.

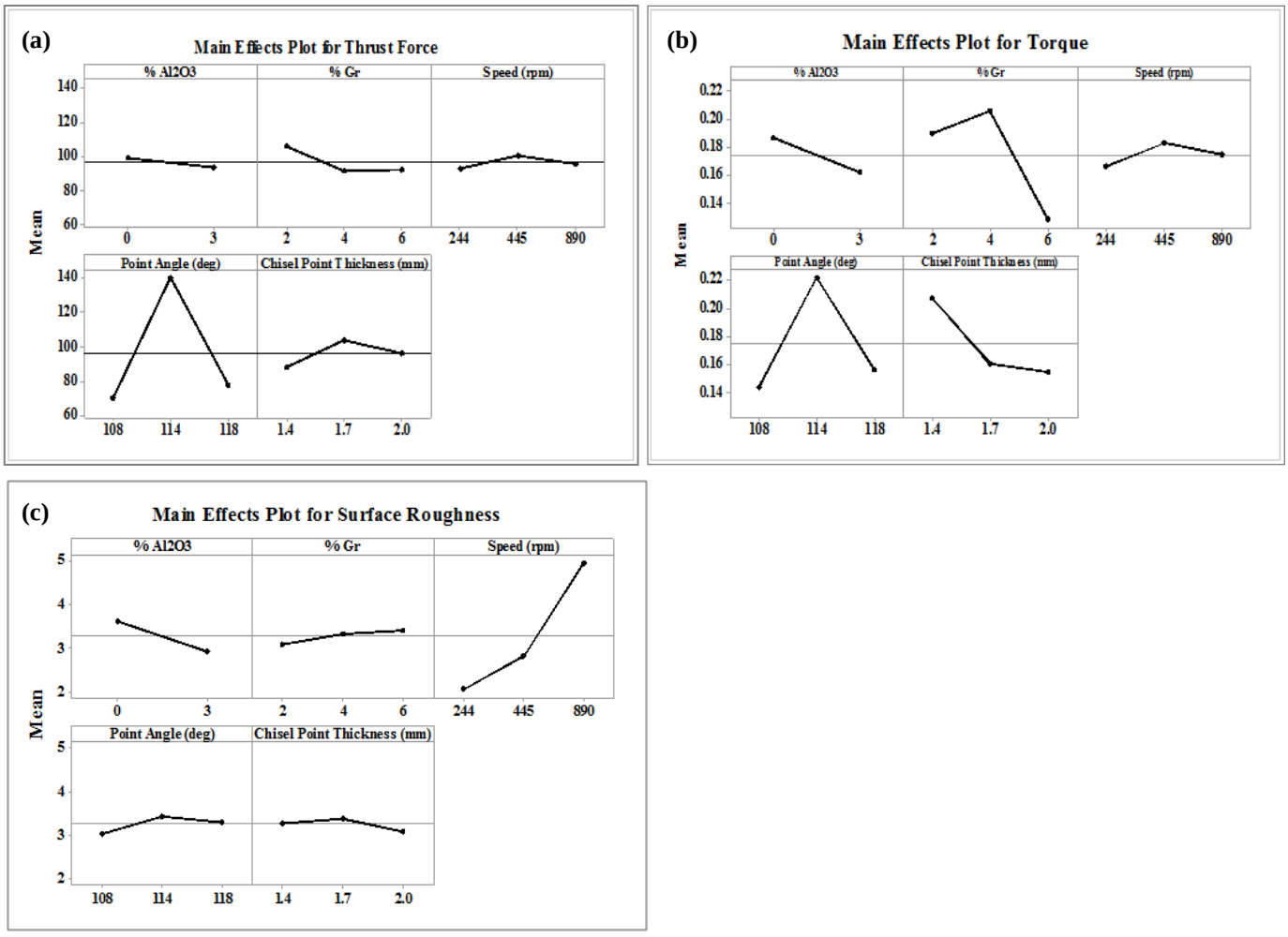

Fig.1 Main effects plots for (a) Thrust Force (b) Torque (c) Surface Roughness

Table 2 ANOVA of TF, TQ and SR

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(a) Thrust Force (TF)							
Source	DF	Seq SS	Adj SS	Adj MS	% contribution	F-tested	F-value
% alumina	1	125.8	125.8	125.82	0.53 %	0.24	0.636
% Gr	2	813.7	813.7	406.86	3.43%	0.78	0.490
speed	2	163.4	163.4	81.69	0.68%	0.16	0.857
point angle	2	17871.8	17871.8	8935.89	74.78%	17.17	0.001
chisel point thickness	2	759.0	759.0	379.52	3.17%	0.73	0.512
Residual Error	8	4163.1	4163.1	520.39	17.42%		
Total	17	**23896.9**			100%		
(b) Torque (TQ)							
% alumina	1	0.002665	0.002665	0.002665	4.06%	1.88	0.208
% Gr	2	0.020337	0.020337	0.010169	30.78%	7.16	0.016
speed	2	0.000825	0.000825	0.010169	1.24%	0.29	0.755
point angle	2	0.020900	0.020900	0.010450	31.63%	7.36	0.015
chisel point thickness	2	0.009983	0.009983	0.004991	15.10%	3.52	0.080
Residual Error	8	0.011359	0.011359	0.001420	17.19%		
Total	17	**0.066069**			100%		
(c) Surface Roughness (SR)							
% alumina	1	2.1743	2.1743	2.1743	6.96%	20.10	0.002
% Gr	2	0.3211	0.3211	0.1606	1.02%	1.48	0.283
speed	2	27.1108	27.1108	13.5554	89.74%	125.29	0.000
point angle	2	0.4438	0.4438	0.2219	1.42%	2.05	0.191
chisel point thickness	2	0.2920	0.2920	0.1460	0.93%	1.35	0.313
Residual Error	8	0.8655	0.8655	0.1082	2.77%		
Total	17	**31.2075**			100%		

4.2 INFLUENCE OF CUTTING PARAMETERS ON TQ

It is observed that the TQ is maximum during the entry of the drill bit into the composite work piece and then it drops to the minimum value. The maximum values are taken for analysis. From table 2 and Fig.1, it is observed that TQ is mainly affected by wt.% Gr (30.78%) and point angles (31.63%). The TQ has the decreasing trend with increase of %Gr. This may be due to the natural lubricant property of the reinforcement, which will ease machining. This helps in shearing the material along the shear plane and reducing the shear flow stress. Also, pointTQ has resulted in higher value for point angle 108^0 than point angle 114^0. Later, it dropped again for point angle 118^0. This may be due to interactive effect of %Gr which act as the natural lubricant during the drilling and ease the machining.

4.3 INFLUENCE OF CUTTING PARAMETERS ON SR

Table 2 shows the results of the ANOVA of SR. It is observed from Table 2 that the % alumina (6.96%) and the speed (89.74%) have statistical significance on the SR. The statistical significance of other parameters is minimum and it can be neglected. The SR is decreasing due to addition of the alumina. This may be due to the burnishing effect caused by the action of small reinforcing alumina particles trapped between the flank of the drilling tool and the composite surface. Also the SR is increasing with the increase of the speed. At higher speeds, the cutting forces and the temperature during drilling operation increases. Consequently, the bonding strength between the reinforcing particles and the matrix weakens and the particles are easily pulled out of the matrix. This results in increase of SR. The results are in agreement with the researchers [--].

5. CONCLUSIONS

Aluminum 7075 HMMCs were fabricated successfully through stir casting route. Uniform distribution of reinforced particles alumina and graphite is confirmed through SEM views. Holes were drilled on the hybrid composites using Ø10mm diameter drill bit with different point angles and chisel point thickness. The following conclusions were drawn from the analysis of various observations,

- It is observed from ANOVA that point angles contribute significantly to the thrust force.

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- The wt% of graphite and point angles are significant for the torque. The trend of the torque is decreasing with the wt% of graphite.
- The variation of thrust force and torque is similar with the given point angles. Both are increasing initially and then decreasing with point angles.
- The wt.% alumina and speed are significant for surface roughness. The surface roughness decreased with increase of wt. % of alumina. It increases with increase of the speed.
- Analysis of the machined surface of these composite shows that some of the reinforcing alumina and graphite particles are pulled out of the drilled surface, while others become fractured during the drilling operation.

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